

For Delivery at: "Les Droits de l'Homme and Scientific Progress
A Symposium Sponsored by The Smithsonian
Institution and The National Academy of
Sciences

Maxine F. Singer

October 27, 1989

The word frontier is used repeatedly to describe original scientific work. Scientists who do such work are frequently called pioneers. But excessive use has dulled the impact of these descriptions. As metaphors for science they have become tiresome and empty.

In 1944, when the words were used by Franklin Delano Roosevelt, President of the United States, and Vannevar Bush, President of the Carnegie Institution of Washington and Roosevelt's war-time science advisor, they signified an inspiring vision for the future. In mid-November of that year, 45 years ago, Roosevelt wrote to Bush:

"New frontiers of the mind are before us,
and if they are pioneered with the same
vision, boldness, and drive with which we
have waged this war, we can create a fuller
and more fruitful employment and a fuller
and more fruitful life."

Continuing, Roosevelt asked Bush how the lessons, learned from coordinating the nation's scientific effort during World War II, could be employed in peacetime. Bush's formal response came in July of 1945. It was entitled "Science, the

Endless Frontier" and it established a framework for American science that has lasted for almost half a century. Bush's vision had two components. One was the establishment of the National Science Foundation. In 1950 the dream was realized, and the Foundation, along with the contemporaneous growth of the National Institutes of Health, demonstrated the United States' commitment to foster research in the national interest, broadly conceived. The second component of Bush's vision was the idea of science as frontier.

From the first settlement of the new world until the early years of the 20th century, geographic frontiers, the move westward, provided unlimited opportunities for succeeding generations of Americans and for new immigrants alike. Serious scholarly analysis of the frontier is said to have begun with publication of Frederick Jackson Turner's paper "The Significance of the Frontier in American History" in 1893. And for many years, Turner's frontier hypothesis was the framework for American historians. It is almost certainly Turner's ideas that Roosevelt and Bush had in mind when they used the words pioneer and frontier.

But, even by 1945, Turner's hypothesis was being seriously questioned. That notion of frontier is, in words phrased by A.B. Giamatti, a romantic "nostalgia, masquerading as historical memory," had begun to fade under more realistic historical examination. Yet, the romanticism persists today. Its elements are surely condensed into the continuing metaphoric use of the words: 'frontier and pioneer' for science.

However, current concepts about the historical frontier provide a complex and more illuminating metaphor for contemporary biological research and the culture in which it thrives, than did the romance. By examining science in this new frontier context we can perhaps dispel some of the popular romanticism, a curious mixture of awe, dependence, and fear. Science, like the geographic frontier, will then be more realistically understood.

In this talk I will use several aspects of the historical frontier as background for illustrating contemporary biological research and its interaction with and impact on the world at large.

One of the frontier myths holds that pioneer society was overwhelmingly youthful. A foreign visitor to Chicago in about 1845, when the city was just emerging, recalled that he saw "neither an old man nor a gray hair" (W.A. Williams). In science too, productivity seems to go with youth. Young people populate biology labs, providing hard work, originality, and irreverence. Several of the most important discoveries of the last 4 decades were made by very young people.

For example, the prediction in 1964, of the existence of reverse transcription, the copying of RNA molecules into DNA, was made by Howard Temin, then 30 years old. The notion challenged what was called "the central dogma," that biological information flows unidirectionally from DNA to RNA to protein.

The confirmation of Temin's prediction came 6 years later when Temin, and independently, David Baltimore, then age 32 demonstrated that retroviruses encode a reverse transcriptase enzyme. Yet, as important as the work seemed, in 1970, its full significance was hardly discerned. Now we know, from the work of both young and older biologists, that reverse transcription is not restricted to viruses, but is encoded in cells. Substantial portions of chromosomal DNA originated as reverse transcripts. Many of the transposable elements in the DNA of a wide range of organisms move by processes utilizing reverse transcriptases that the elements encode. Moreover, some recent and highly plausible hypotheses about the origins of cellular processes and coding systems suggest that RNA not DNA was the first informational nucleic acid on the planet, and that reverse transcriptase was an early enzyme, responsible for converting the initial life forms to our ancestral DNA organisms.

The vitality of research depends on a steady flow of young minds and hands. The astonishing expansion of our understanding of life on the planet over the last 40 years was fueled by a panoply of fellowship opportunities, by the federal government in the United States, and by private foundations, fellowships at both pre-doctoral and post-doctoral levels. Sustaining a frontier requires that these continue. But sustaining the frontier also requires a steady if not increasing population of gifted students to take up the fellowships. Here, we in this country face great difficulties. Dozens of blue-ribbon panels have concluded that at the elementary and secondary school levels, American children

receive inadequate instruction in science. Of the few that enter college intending to major in science, many fall by the wayside, finding their earlier preparation inadequate or the teaching unattractive, or both.

Faculties all over the country report a decline in the quality of students at pre- and postdoctoral levels. American industry finds it increasingly difficult to find qualified engineers, technicians, and scientists. Everyone agrees that we have a crisis.

Many things can be said about this crisis. What I would like to stress today is only one of them, the one that reminds us that neither the historical nor the scientific frontiers can succeed with youth alone. Aside from continuing research, special responsibilities devolve onto older scientists, including the responsibility for science education. Walter E. Massey, President of the American Association for the Advancement of Science, recently put the case sharply in an article in Science Magazine. He urges that scientists and engineers make significant personal and institutional commitments to science education. And it is really only the more established scientists that have access to the resources and clout that can get this accomplished.

There are of course other vital activities (a dizzying number of these) for those no longer describable as youths: to continue their research, to enrich their own and their students research with experience, memory of the literature, with wisdom and criticism, to edit journals, to run departments, to serve

on the committees that provide the infrastructure so vital to research. Many senior people are in fact too busy, the demands on their time too great to permit thoughtful actions. And, besides these obvious and essential contributions, events of the last few years highlighted another, less frequently recognized responsibility: to transmit to new generations the ethical foundations of the scientific community. These foundations, or standards, derive from the nature of science itself. Without scrupulous honesty and rigorous self-criticism, science fails. To increase understanding of nature requires that nature be confronted squarely, as impartially as possible. Sadly, breaches in these standards have occurred in the last few years and any delinquency diminishes the scientific endeavor in fact and in name. We have learned to our deep regret that powerful people and people seeking to be powerful are ready to use the breaches, rare though they are, and even allegations of breaches, to condemn the enterprise. They are aided by the deep public misunderstanding and consequent distrust of intellectual endeavors in general and scientific endeavors in particular in our country, phenomena that have existed since the nation was new. There is no question about the fundamental integrity of current scientific research. The evidence lies in the science itself, and its magnificent and uncontrovertible discoveries. Yet, many in the scientific community recognize a diminishing awareness of the broadly consensual standards. Those who teach, the more senior members of the community, should teach not only the science, but, by example and persuasion, the underlying ethical demands.

William A. Williams, talking of the frontier days in the upper Mississippi Valley, in his book The Contours of American History makes a stimulating comment in this regard:

(The frontier brought) "wealth, political freedom and social acceptance.....but it also produced a paradoxical mystique. One half of it was as hard-souled as any in the world, with one eye roving for the next unclaimed watering-place or likely looking acreage and one hand on a gun. Though the other half was in contrast warm and humane and cooperative, its fundamental nature was one that encouraged the evasion of the less obvious but subtly vital problems of social and personal relations."

Another aspect of the historical frontier that illuminates science is the question of expansion. Three elements at least, are important in defining the direction of geographic expansion: the discovery of routes, the ease of following the paths, and the bounty to be found upon arrival. The same is true in biological research. The success of molecular genetics in so many areas of biology over the past fifteen years illustrates the point. New methods opened routes to long standing questions: the methods used to study microbial genetics and bacteriophage, recombinant DNA techniques (that is, molecular cloning), DNA sequencing, increasingly powerful

separation methods for biological macromolecules, advanced immunological methods including monoclonal antibodies, and most recently the polymerase chain reaction. Along the way, the more difficult, tedious versions of the techniques have been replaced by rapid, often automated methods that anyone can master. And the bounty has been great. We now manipulate genes as chemical entities, not abstract ideas. Fundamental new discoveries are announced almost daily...if not flashy enough, or clinical enough for the New York Times, then certainly interesting enough to biologists to be reported in Science or Nature Magazine.

But expansion, like youth needs to be tempered. In the American west, the exploitation of natural resources and the conquest of indigenous populations left a legacy of formidable, baffling problems. Arrogant assumptions about the territory and people being invaded exacerbated the inevitable difficulties. This suggests a parallel with molecular genetics. The nature of the changes in genetics that started in the late 1940s and continued into the 50s and 60s, in particular the remarkable discoveries of the phage group, were seen as an invasion of biochemistry's territory. The perceived, and sometimes actual arrogance of the invaders, together with the perceived and sometimes actual arrogance of those who felt invaded inhibited the formation of bridges between the two disciplines. When finally built, those bridges, like the railroad out west, sped expansion and financial support. A similar situation still exists at the interface between molecular genetics and those

biologies that deal with whole organisms and populations. There are some signs that bridges are abuilding. There is hope that the arid debates over reductionism versus holism will abate. When this happens, we will see another great leap in our understanding of nature.

Frontier people clashed with the society they left behind as well as the peoples they displaced. The same is true for biologists, although those left behind and those displaced are, in a sense, one and the same. Modern biologists have a profoundly mechanistic view of living things, and see humans as one among many species that share the planet. We have no choice in the face of what we are learning. We know that a cloned human gene, introduced into yeast, can cure the yeast cell of a genetic disease caused by a mutation in the orthologous yeast gene. We are startled when challenged by the very different, deeply-held ideas of our fellow citizens, as we now see world-wide with respect to the application of the fundamental discoveries to real problems, including the treatment of disease be it in humans or plants. In the United States the issues are most sharply raised with respect to the study of reproductive biology. Two major thrusts drive current research. One is a desire to understand the development of fertilized eggs into complex organisms. The other is a desire to put biology at the service of human problems: the societal and ecological problems engendered by overpopulation on the one hand and the individual problem of infertility on the other. Sadly, these well

motivated desires have become intricately associated with the wrenching national debate about abortion, which is itself, unhappily, a political debate rather than a serious dialogue about difficult, ultimately personal issues. Disassociation of the abortion question from research on in vitro fertilization and from investigations with early embryonic or fetal tissue is essential to fulfilling the promise of modern biology.

Finally, we need to consider the American national belief that frontier means freedom. And it did stand for freedom...for some. For others, the situation was different....the Indian tribes that lived in the space....the Chinese laborers who built the railroads, to mention only the most obvious. Biologists probably more than other scientists, just because we deal with living things, need to consider that one person's freedom....to discover, may be seen as diminishing the freedom of others. There are various ways to look at this tension. One, of course, is to deny its existence. Another is to try to legislate it out of existence. Yet another is to recognize the rich opportunity it provides, as the modern historians of the western frontier are doing. If we do that for biology, we stand a chance of sustaining the frontier and at the same time ameliorating human problems. Therefore, I opt for living with the tensions.

Consider the question of freedom, blemished though it is. The frontier idea still stands for Americans as a reminder

of the significance of freedom. With the geographic frontiers behind us, what frontier ensures a lasting testimonial, strong enough to preserve that fragile and vulnerable thing we call freedom. Science, the expansion of knowledge through fundamental research remains a frontier, complex, but endless and likely the only frontier left to explore. In the past, science stood as a reminder of freedom as well as requiring freedom for its success. In worrying, properly, about the way that scientific progress can threaten human rights, we should remember that science, and the human culture in which it thrives, confirms and affirms the value of freedom. In those same dark days of the early 1950s, when the idea of freedom was so threatened in the United States by Joseph McCarthy and his followers, freedom was affirmed in the designs for how the National Science Foundation and the National Institutes of Health would work. Individual scientists were encouraged to put forward their own ideas for evaluation rather than being instructed as to what research to pursue. The fruits of this system are obvious to all who look.

The potential threat to this freedom is what worried some of us about recent end-runs around the peer review system by some misguided universities. The same threat exists in attempts to dictate how science should be done---be they through centralized decisions about research directions in the human genome project, or through catastrophic confusion about the difference between wrongdoing and error in scientific work. And the threat appears in talk of banning some kinds of research.

There are other less stultifying and more effective ways to reach consensus on if and when certain techniques should be applied.

Vannevar Bush's image of science as the endless frontier endures. Although the image has lost its utopian cast, it remains visionary and bold. Science, the remaining frontier, testifies to the tension between freedom and responsibility.

In closing, I will read some words of A. Bartlett Giamatti, who understood better than anyone else I have known, why learning, that is research, is at the core of being human and being free. A humanist, he said:

"From the scientists, social and natural, we derive our belief in the unifying force of the search for knowledge, and in the harmonies among forms of knowledge, even as knowledge, increasing, tends to fragment itself and us with it. From them we learn what we should never forget, that to view nature justly, nature human and material, we must eschew parochialism and casual labels and bureaucratic boundaries, and seek to see the truth from as many vantage points as humankind can summon."

A.B. Giamatti, *The University and the Public Interest*. Atheneum. New York, 1981.

W.A. Williams. *The Contours of American History*. Norton and Co. 1988.

W.E. Massey. 1989. *Science Education in the United States: What the Scientific Community Can Do*. Science 245 915-921.